US007446860B1

(12) **United States Patent**
Campbell et al.

(10) **Patent No.:** **US 7,446,860 B1**
(45) **Date of Patent:** **Nov. 4, 2008**

(54) **LASER FRESNEL DISTANCE MEASURING SYSTEM AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 31 days.

(21) Appl. No.: **11/527,648**

(22) Filed: **Sep. 18, 2006**

(51) **Int. Cl.**
G01C 3/08 (2006.01)

(52) **U.S. Cl.** **356/4.03**

(58) **Field of Classification Search** 356/3.01–3.15, 356/4.01–4.1, 5.01–5.15, 6–22, 28, 28.5
See application file for complete search history.

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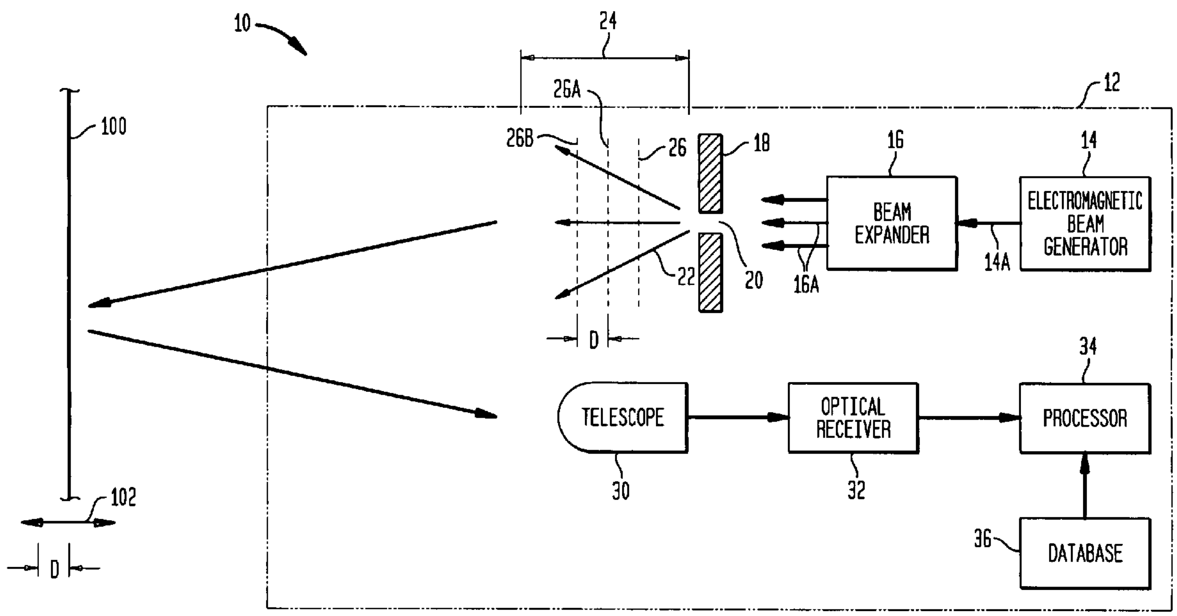
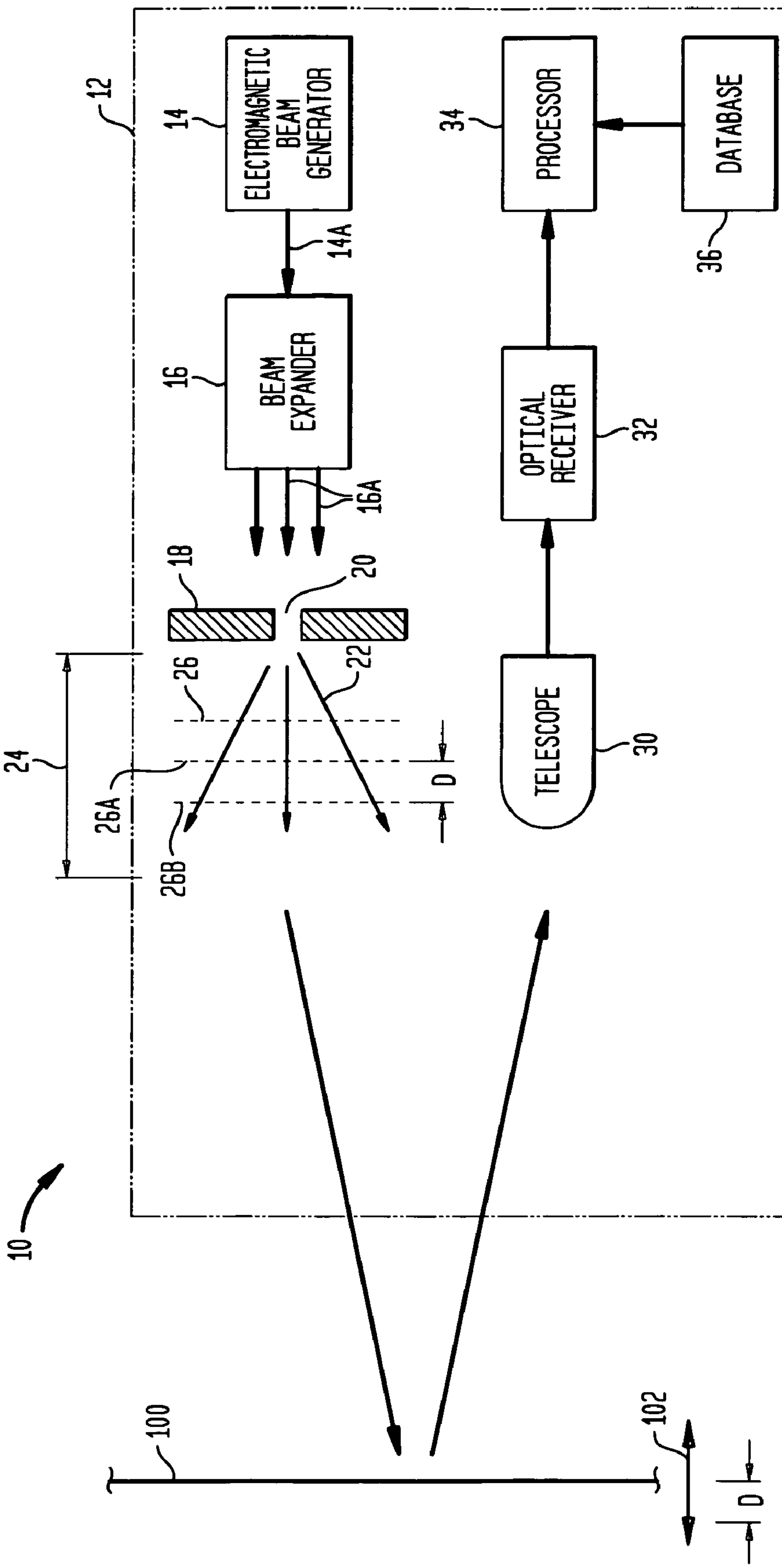
(57) **ABSTRACT**

A method and system for determining range to a target are provided. A beam of electromagnetic energy is transmitted through an aperture in an opaque screen such that a portion of the beam passes through the aperture to generate a region of diffraction that varies as a function of distance from the aperture. An imaging system is focused on a target plane in the region of diffraction with the generated image being compared to known diffraction patterns. Each known diffraction pattern has a unique value associated therewith that is indicative of a distance from the aperture. A match between the generated image and at least one of the known diffraction patterns is indicative of a distance between the aperture and target plane.

29 Claims, 2 Drawing Sheets

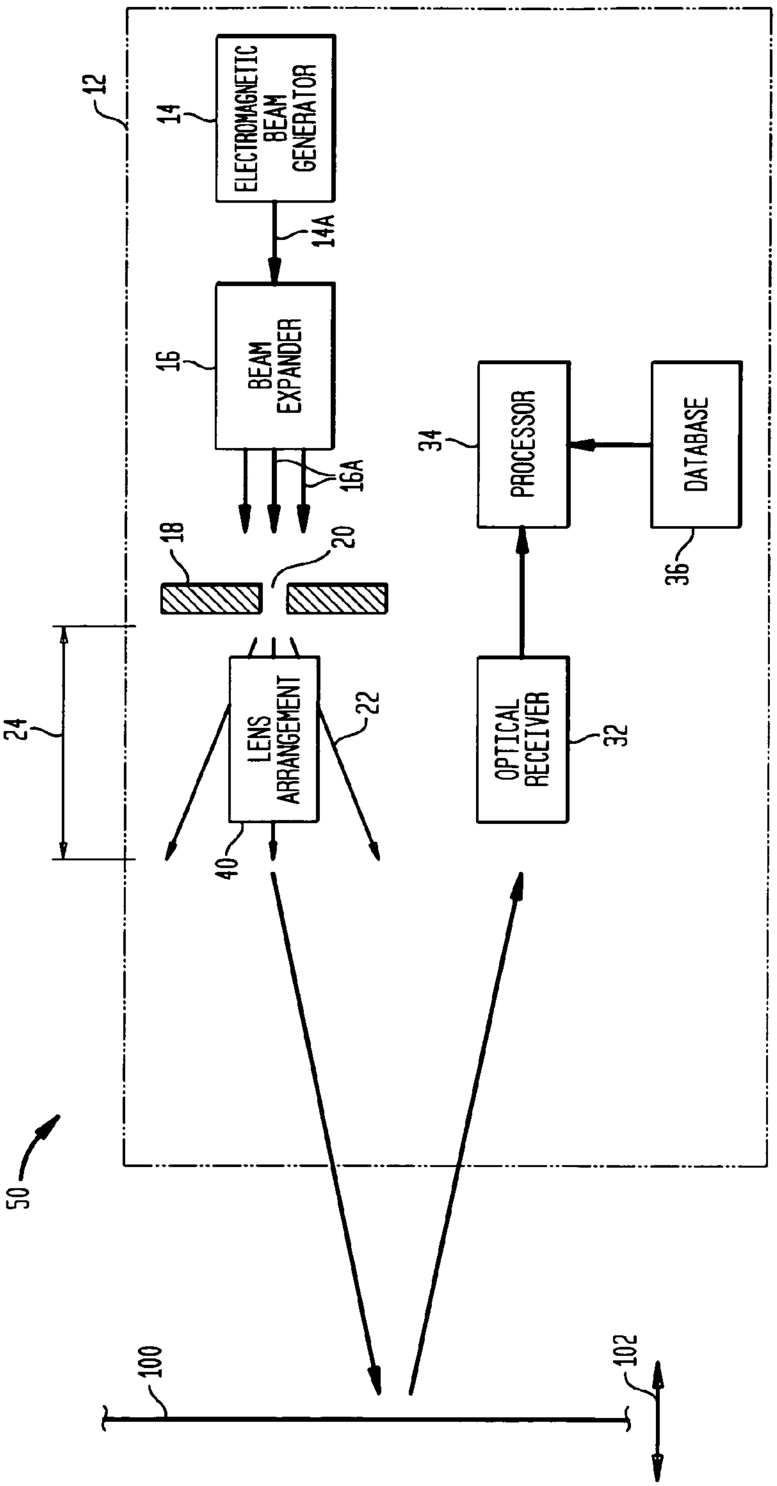




ELECTROMAGNETIC BEAM GENERATOR
BEAM EXPANDER
PROCESSOR
DATABASE
OPTICAL RECEIVER
TELESCOPE
D
D
10
12
14
14A
16
16A
18
20
22
24
26
26A
26B
30
32
34
36
100
102

FIG. 1

FIG. 2


12
14
ELECTROMAGNETIC BEAM GENERATOR
14A
16
BEAM EXPANDER
16A
18
20
24
LENS ARRANGEMENT
22
40
34
PROCESSOR
DATABASE
36
OPTICAL RECEIVER
32
50
100
102

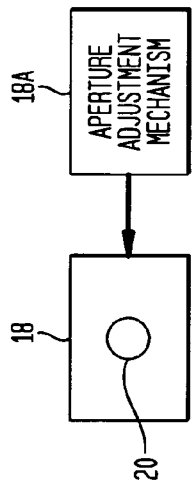

18A
APERTURE ADJUSTMENT MECHANISM
18
20

FIG. 3

LASER FRESNEL DISTANCE MEASURING SYSTEM AND METHOD

ORIGIN OF THE INVENTION

The invention described herein was made in performance of work under a NASA contract and by an employee of the United States Government and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, as amended, Public Law 85-568 (72 Stat. 435; 42 U.S.C. §2457), and 35 U.S.C. §202, and may be manufactured and used by the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore. In accordance with 35 U.S.C. §202, the Contractor elected not to retain title.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to high-precision distance measuring systems and techniques. More specifically, the invention is a high-precision, laser Fresnel distance measuring system and method.

2. Description of the Related Art

Non-intrusive and highly accurate determination of distance to a "target" with a precision on the order of a micron or less would be useful in a variety of industrial, commercial, and government-related applications. For example, large adaptive mirrors used in space or ground applications require knowledge of the location of mirror segments to a very high precision in order to make corrections to an optical wavefront.

Conventional high-precision rangefinders can use lasers and complex processing systems/algorithms. For instance, U.S. Pat. No. 6,456,383 discloses a method and apparatus for making absolute distance measurements using Fresnel diffraction. Briefly, after a laser beam is reflected by a target, the reflected beam is passed through an aperture. A detector spaced from the aperture detects the central intensity of the beam (passed through the aperture) as well as intensities displaced from the beam's center. The intensities are then used to calculate the distance to the target using complex mathematical relationships. However, this system is limited to determination of distances on the order of a few centimeters.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method and system for determining distance to a target.

Another object of the present invention is to provide a method and system for determining distance to a target with a precision on the order of a micron or better.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a method and system for determining distance to a target are provided. A beam of electromagnetic energy is transmitted through an aperture in an opaque screen such that a portion of the beam passes through the aperture to generate a region of diffraction (e.g., a Fresnel region) that varies as a function of distance from the aperture. An imaging system is focused on a target plane in the region of diffraction to generate an image of the target plane. The generated image is compared to a plurality of known diffraction patterns with each known diffraction pattern having a unique value associated therewith that is indicative of a distance from the aperture. A match between the generated image and at least one of the known diffraction patterns is indicative of a distance between the aperture and target plane.

BRIEF DESCRIPTION OF THE DRAWING(S)

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. **1** is a schematic view of a laser Fresnel distance measuring system in accordance with an embodiment of the present invention;

FIG. **2** is a schematic view of a laser Fresnel distance measuring system in accordance with another embodiment of the present invention; and

FIG. **3** is an isolated schematic view of the system's opaque screen equipped for aperture size adjustment.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring now to the drawings and more particularly to FIG. **1**, a laser Fresnel distance measuring system in accordance with the present invention is shown and is referenced generally by numeral **10**, the optical elements of which can be affixed to a platform **12**. System **10** can be used in a wide variety of applications. Accordingly, it is to be understood that any references made herein with respect to specific applications are not limitations of the present invention.

System **10** includes an electromagnetic beam generator **14** (e.g., laser) mounted on platform **12** and capable of producing a beam **14**A of electromagnetic energy. Depending on the approach used, beam generator **14** can be realized by (i) a single laser producing a single-wavelength laser beam, (ii) multiple lasers arranged to output their respective beams onto a shared optical path to produce beam **14**A, or (iii) a tunable laser capable of outputting a variable-wavelength beam **14**A.

In the illustrated embodiment, beam **14**A is passed through a beam expander **16** (mounted on platform **12**) to produce a parallel wavefront beam represented by parallel arrows **16**A. Parallel wavefront beam **16**A is incident on an opaque screen **18** mounted on platform **12**. In general, a portion **22** of beam **16** passes through an aperture **20** formed through screen **18**. After passing through aperture **20**, portion **22** undergoes diffraction within a region that lies between lines **24**. In terms of the present invention, diffraction region **24** is any region of diffracted radiation behind aperture **20** that is predictable and demonstrates a unique intensity pattern as a function of distance from aperture **20**. Thus, the optical pattern of the diffraction region at a target plane (e.g., the target plane represented by dashed vertical line **26**) located in diffraction region **24** varies with the distance between that target plane and aperture **20**. By way of example, if the electromagnetic energy incident on screen **18** is parallel wavefront beam **16**A, diffraction region **24** is a Fresnel diffraction region as is well known in the art.

Another of the optical elements fixedly mounted on platform **12** is a telescope **30** having a shallow or narrow depth-of-field focused on some plane in diffraction region **24**. More specifically, the focal path length of telescope **30** includes the path to a reflective surface **100** and the path from reflective surface **100** to some target plane in diffraction region **24**. Thus, telescope **30** and reflective surface **100** are part of an

imaging system used to view a target plane in diffraction region **24**. If telescope **30** has a shallow or narrow depth-of-field, the focal plane imaged by telescope **30** is similarly narrowly defined. As will become more apparent later in the description, the "shallowness" of the telescope's depth-of-field should be commensurate with the precision required of the distance that is to be measured.

Reflective surface **100** is representative of the surface of an object of interest that will experience movement referenced by two-headed arrow **102**. The distance moved as a result of movement **102** is to be measured with a high degree of precision. The reflective nature of surface **100** can be inherent in the object experiencing movement **102** (e.g., a mirror). However, the reflective nature of surface **100** could also be provided by attaching a mirror to a non-reflective object of interest (not shown) to define reflective surface **100**, or by reflectively coating the object of interest.

The image "viewed" by telescope **30** is provided to an optical receiver **32** (e.g., an image detector) that prepares the image for processing by a processor **34**. Coupled to or integrated with processor **34** is a database **36** that stores known Fresnel diffraction patterns along with an associated unique distance at which each such pattern would be generated with the given arrangement of optical elements used to generate diffraction region **24**. Receiver **32**, processor **34** and/or database **36** can be located/mounted on or off platform **12** without departing from the scope of the present invention.

Each diffraction pattern defining region **24** is a function of the size of aperture **20**, the wavelength of beam **14**A, and the distance from aperture **20**. Thus, for a given arrangement of beam generator **14**, its operating wavelength, and aperture **20**, a set of diffraction patterns from diffraction region **24** can be generated, mapped, and then stored (in database **36**) as a function of distance from aperture **20**.

In terms of measuring an absolute distance that reflective surface **100** moves, system **10** must be calibrated. During calibration, the optical elements of system **10** must remain in a fixed relationship with reflective surface **100**. Since the optical elements of system **10** are typically fixed to platform **12**, reflective surface **100** and platform **12** could be rigidly coupled to one another to achieve the fixed relationship. Once fixed in this fashion, the distance between telescope **30** and reflective surface **100** is measured using any conventional distance measuring tool. This distance becomes the base distance to which a distance change is added/subtracted to determine the absolute distance to reflective surface **100**. Note that if only changes in distance are of interest, the calibration step can be omitted.

To calibrate system **10** while reflective surface **100** and platform **12** are rigidly coupled to one another, diffraction region **24** is generated and telescope **30** is focused on diffraction region **24**. Specifically, a baseline target plane **26**A in diffraction region **24** is imaged by telescope **30** with the location of baseline target plane **26**A being governed by the relative position of reflective surface **100** and "width" or "thickness" of baseline target plane **26**A being governed by the depth-of-field of telescope **30**. The diffraction pattern viewed by telescope **30** is indicative of a baseline distance from aperture **20** to baseline target plane **26**A. This baseline distance is determined by processor **34** via a comparison with the above-described mapped set of diffraction patterns stored in database **36** for the particular arrangement of generator **14**/aperture **20** and the operating wavelength of generator **14**.

When it is time for system **10** to measure the distance that reflective surface **100** moves via movement **102**, the fixed relationship between the optical elements of system **10** and reflective surface **100** is abolished so that reflective surface **100** is free to undergo movement **102** while the optical elements of system **10** remain fixed. System **10** is then operated so that diffraction region **24** is generated and telescope **30** is focused on diffraction region **24** via reflection off reflective surface **100**. The diffraction pattern (within diffraction region **24**) at the focal plane of telescope **30** is indicative of the amount of movement of reflective surface **100**. For example, if reflective surface **100** moves a distance D away from telescope **30** as shown, the target plane focused on by telescope **30** (i.e., target plane **26**B) will also be a distance D from baseline target plane **26**A. In the present invention, distance D can be determined (by processor **34**) by

(i) matching the diffraction pattern at target plane **26**B with one of the stored patterns in database **36** in order to determine its associated distance from aperture **20**, and

(ii) determining the difference between the distance from aperture **20** associated with baseline target plane **26**A and the distance from aperture **20** associated with target plane **26**B.

The present invention is not limited to the particular system described above. For example, another distance measuring system **50** in accordance with the present invention is illustrated in FIG. **2** where the approach and optical elements used to generate diffraction region **24** are the same as described above with respect to system **10**. However, rather than using a telescope to directly image a target plane in diffraction region **24**, a lens arrangement **40** mounted to platform **12** and positioned in diffraction region **24** optically displaces the target plane to optical receiver **32**. For example, lens arrangement **40** can be designed to have a fore and aft focal plane with the fore focal plane being calibrated through an initial calibration procedure (i.e., similar to that described above) to determine its distance to aperture **20** when the optical elements of system **50** are fixed in relation to reflective surface **100**.

In both calibration and operation, the focused diffraction pattern passing through lens arrangement **40** is converted to a parallel wavefront that reflects off reflective surface **100** and onto optical receiver **32** where the parallel wavefront is converted back to an image of the diffraction pattern. That is, the diffraction pattern is optically moved to optical receiver **32**. Thus, as the distance between optical receiver **32** and reflective surface **100** changes, the effective imaging location of receiver **32** in diffraction region **24** also changes. Thus, a different diffraction pattern indicative of such change is imaged by optical receiver **32**. The functions of processor **34** and database **36** are the same as those described with respect to system **10**.

While the present invention can utilize the entire image of a generated Fresnel diffraction pattern, processing speeds and efficiency associated with such "whole image" processing may limit the overall value of the system especially in high frequency applications. Accordingly, the present invention can also be practiced by using only one or more portions of the Fresnel diffraction pattern at a given target plane therein. Several non-limiting examples will be discussed herein.

In a first approach, processor **34** uses just the central portion (e.g., a center pixel) of the Fresnel diffraction pattern at a given target plane. In general and as is known in the art, the intensity of a Fresnel diffraction pattern varies as a function of source distance in accordance with a wavelike or sinusoidal function. Further, this intensity and its variability is greatest at the central portion of a Fresnel diffraction pattern so that even a very small change in source distance results in a detectable change in intensity.

If the range of distances of interest is sized to coincide with a single cycle of the wavelike or sinusoidal function governing the Fresnel diffraction pattern, then the central portion of

the pattern will uniquely define the distance. However, as the range of distances of interest increases, the Fresnel diffraction pattern will undergo multiple cycles so that comparisons using just the intensity of the pattern's central portion produces ambiguous distance measurements. For example, if the range of distances of interest was such that the Fresnel diffraction pattern experienced five cycles over the range, a given intensity of the central portion of the pattern might be repeated five times with each such repeat being indicative of a different distance value. To remedy this ambiguity problem, a second approach of the present invention (e.g., programmed into processor **34**) utilizes a second distinct portion (i.e., another pixel) of the pattern in combination with the central portion of the pattern. That is, processor **34** would compare the central and second portion of the imaged pattern with the corresponding central and second portion of the known patterns stored in database **36**. The distance ambiguity problem is solved by requiring a match between both compared portions.

The ambiguity problem could also be addressed by means of a third approach of the present invention. More specifically, generator **14** could be a variable-wavelength laser capable of generating beam **14**A of different wavelengths. Since the Fresnel diffraction pattern cycle will be unique for each wavelength of beam **14**A and a given aperture **20**, processor **34** could be programmed to collect pattern images at each of two (or more) different wavelengths. The central (or other) portion from each collected pattern/wavelength can then be used during the comparison with known Fresnel diffraction patterns/wavelengths to unambiguously determine distance.

Still further, a fourth approach of the present invention could utilize a single-wavelength laser for generator **14** but vary the size of aperture **20**. For example, as shown in FIG. **3**, screen **18** can have an aperture adjustment mechanism **18**A incorporated with or coupled thereto to make aperture **20** smaller or larger. Since changing the size of aperture **20** changes the Fresnel diffraction pattern cycle, processor **34** could collect and utilize imaged patterns (or portions thereof) for two aperture sizes to unambiguously determine distance.

The advantages of the present invention are numerous. Distance measurements are accurately made without any complex hardware or software. It is only necessary to provide an optical arrangement (e.g., telescope **30**) that has a depth-of-field precision on the order of the precision of the distance changes to be measured. The simple comparison approaches described herein can be implemented with minimal processor complexity without sacrificing measurement accuracy.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. For example, the present invention is not limited to use with Fresnel diffraction as it will work with any radiation field region behind an aperture that is predictable and demonstrates a unique intensity pattern as a function of distance from the aperture.

Still further, should there be a concern about losing the absolute distance information momentarily during operation, the present invention can include a series of platform "stops" at known fixed distances from the screen's aperture. Each "stop" would provide the system with a new baseline distance in the event the system had to be re-started. This will reduce the amount of time lost each time the system must be re-started. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A method of determining range to a target, comprising the steps of:

transmitting a beam of electromagnetic energy through an aperture in an opaque screen such that a portion of said beam passes through said aperture to generate a region of diffraction that varies as a function of distance from said aperture;

focusing an imaging system on a target plane in said region of diffraction wherein an image of said target plane is generated; and

comparing said image with a plurality of known diffraction patterns with each of said known diffraction patterns having a unique value associated therewith that is indicative of a distance from said aperture, wherein a match between said image and at least one of said known diffraction patterns is indicative of a distance between said aperture and said target plane.

2. A method according to claim **1** wherein the imaging system includes a movable reflective surface positioned in the imaging system's focal path wherein changes in distance between said aperture and said target plane are indicative of an amount of movement of the movable reflective surface.

3. A method according to claim **1** wherein said step of imaging includes the step of focusing a telescope on said target plane.

4. A method according to claim **1** wherein said step of imaging includes the step of optically displacing a portion of said region of diffraction located at said target plane to the imaging system generating said image.

5. A method according to claim **1** wherein said step of comparing utilizes a portion of said image.

6. A method according to claim **5** wherein said portion of said image coincides with a central portion of said region of diffraction.

7. A method according to claim **1** wherein said electromagnetic energy is defined by a single wavelength, and wherein said step of comparing utilizes two different portions of said image.

8. A method according to claim **1** further comprising the step of performing said steps of transmitting, focusing and comparing for at least two different sizes of said aperture.

9. A method according to claim **1** further comprising the step of performing said steps of transmitting, focusing and comparing for at least two different wavelengths of said electromagnetic energy.

10. A method of determining range to a target, comprising the steps of:

transmitting a beam of electromagnetic energy through an aperture in an opaque screen such that a portion of said beam passes through said aperture to generate a Fresnel region of diffraction;

focusing an imaging system on a target plane in said Fresnel region wherein an image of said target plane is generated; and

comparing said image with a plurality of known Fresnel diffraction patterns with each of said known Fresnel diffraction patterns having a unique value associated therewith that is indicative of a distance from said aperture, wherein a match between said image and at least one of said known Fresnel diffraction patterns is indicative of a distance between said opaque screen and said target plane.

11. A method according to claim **10** wherein the imaging system includes a movable reflective surface positioned in the imaging system's focal path wherein changes in distance

between said aperture and said target plane are indicative of an amount of movement of the movable reflective surface.

12. A method according to claim **10** wherein said step of imaging includes the step of focusing a telescope on said target plane.

13. A method according to claim **9** wherein said step of imaging includes the step of optically displacing said target plane in said Fresnel region to an imaging system generating said image.

14. A method according to claim **10** wherein said step of comparing utilizes a portion of said image.

15. A method according to claim **14** wherein said portion of said image coincides with a central portion of said Fresnel region.

16. A method according to claim **10** wherein said electromagnetic energy is defined by a single wavelength, and wherein said step of comparing utilizes two different portions of said image.

17. A method according to claim **10** further comprising the step of performing said steps of transmitting, focusing and comparing for at least two different sizes of said aperture.

18. A method according to claim **10** further comprising the step of performing said steps of transmitting, focusing and comparing for at least two different wavelengths of said electromagnetic energy.

19. A system for determining range to a target, comprising:

means for generating a beam of electromagnetic energy;

an opaque screen positioned in the path of said beam, said opaque screen having an aperture formed therethrough such that a portion of said beam passes through said aperture to generate a region of diffraction that varies as a function of distance from said aperture;

imaging means for generating an image of a target plane in said region of diffraction; and

processing means coupled to said imaging means for comparing said image with a plurality of known diffraction patterns with each of said known diffraction patterns having a unique value associated therewith that is indicative of a distance from said aperture, wherein a match between said image and at least one of said known diffraction patterns is indicative of a distance between said opaque screen and said target plane.

20. A system as in claim **19** wherein said imaging means includes a movable reflective surface positioned in the imaging system's focal path wherein changes in distance between said aperture and said target plane are indicative of an amount of movement of the movable reflective surface.

21. A system as in claim **19** further comprising a platform to which said means for generating, said opaque screen, and portions of said imaging means are fixedly coupled.

22. A system as in claim **19** wherein said imaging means includes a telescope focused on said target plane.

23. A system as in claim **19** wherein said imaging means comprises:

an imager adapted to be positioned away from said region of diffraction; and

an optical lens arrangement adapted to be positioned in said region of diffraction for optically displacing a portion of said region of diffraction located at said target plane to said imager.

24. A system as in claim **19** wherein said means for generating comprises at least one laser.

25. A system as in claim **19** wherein said means for generating comprises a single-wavelength laser.

26. A system as in claim **19** wherein said means for generating comprises a variable-wavelength laser.

27. A system as in claim **19** wherein said aperture is a circular aperture.

28. A system as in claim **27** wherein said means for generating includes means for forming said beam as a parallel wavefront beam prior to incidence on said opaque screen, wherein said region of diffraction comprises a Fresnel region of diffraction.

29. A system as in claim **27** further comprising means for adjusting the size of said circular aperture.

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